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Detection and Removal of Short-circuits on GEM-foils

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Abstract

High resolution scanning system was used to locate the areas on GEM-foils that might contain short-circuit. These areas were analyzed by threshold method for fast identification. Different methods to remove short-circuits on GEM-foils were studied. Since using the standard procedure of "burning" shorts with high current might incur additional damage to the foil, we have also studied several non-destructive methods. These methods were for example washing with high power ultrasonic, manual extirpation and by using resonance frequencies. We will show results on locating and removing the GEM-shorts from standard bi-conical 10 cm × 10 cm foils.

Keywords: GEM; short-circuit; optical scanning system

1. Introduction

Standard CERN manufactured GEM-foil [1] consists of 50 µm thick polyimide with 5 µm copper layer clad on the surfaces. It has high density of chemically etched bi-conical holes with pitch of 140 µm, outer diameter of 70 µm and inner diameter of 50 µm. When a voltage potential difference is set between the surfaces, each hole operates as an individual signal amplifier. The gain of the holes in dependent on the potential difference set on the surfaces and on the size and shape of the holes [2]. Several foils can be used in cascade to increase the overall gain of the detector. For efficient detection of minimum ionizing particles in thin layers of gas, gain of several thousand is required [3]. At this value of gain, exposure to

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high radiation fluxes, or the release of a large amount of charge in the sensitive volume may induce a breakdown of the gas rigidity. This will eventually lead to streamer formation when the avalanche size exceeds the Raether limit of 10^7 electron-ion pairs followed by discharge spark. The intensity of the discharge can be high enough to carbonize the polyimide inside the holes. The carbonized polyimide will act as conductor connecting the copper surfaces in short circuit.

The Raether limit is determined by the charge density in the avalanche and its ratio with respect to the surface charge density on the detector electrodes [4]. When the number of primary electrons is small the breakdown is due to combination of several effects such as the impurities originating from the manufacturing and handling of the foils. These include microscopic particles that attach to the foil surface with static electricity. Figure 1 shows some examples of particles that are found from the foils. In some occasions the dust particles can have contact with both electrodes creating a path for a formation of a short circuit. This type of dust can be seen in the lower left image in Fig. 1. The microfiber seen on lower right seems to either contributed in the deformation of the hole or formed due to the deformation of the hole. The image on upper right shows dried remnant left from manufacturing blocking several holes. This type of dirt might damage the foil when it is irradiated.

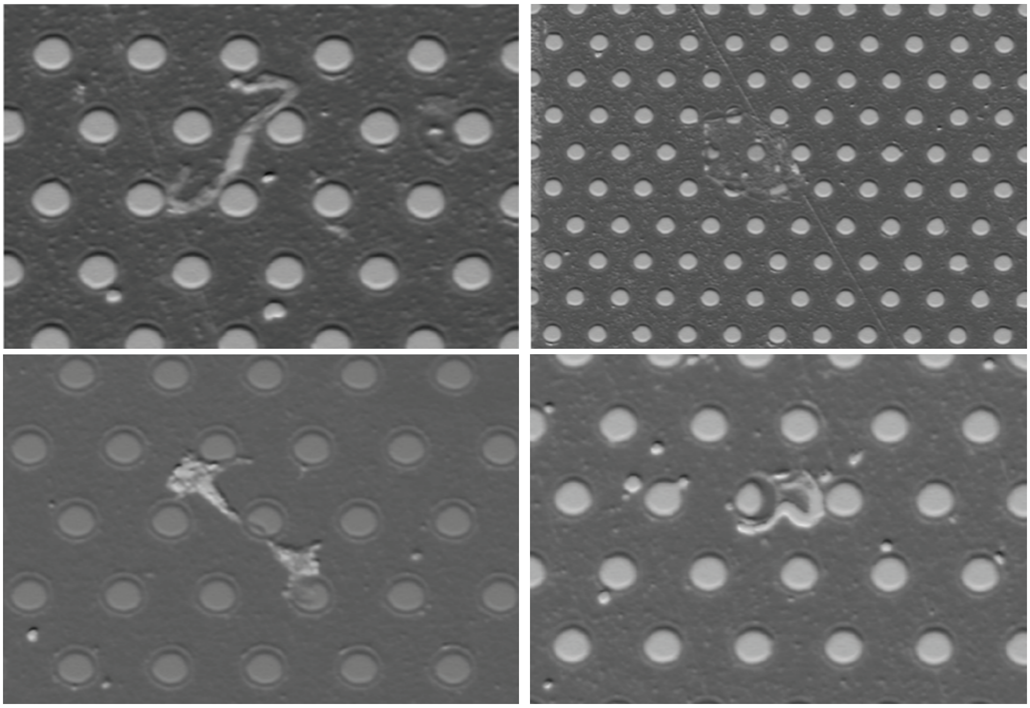

Fig. 1 Different dust particles located on the surface of GEM-foils. Dust on images on upper left and bottom row is microscopic fibers that have been located on foil surfaces. The image on up right shows a dried remnant of solutions that were used in foil manufacturing blocking several holes.

2. Locating the Short-circuits

Standard bi-conical 10 cm × 10 cm GEM-foil has resistivity of over 2 GΩ between the sides of the foil in dry air. The resistivity cannot be measured directly due to the properties of polyimide. Instead the foil is attached to a circuit with picoammeter measuring the leakage current going through the foil. In our setup the leakage current is measured with Keithley 487 picoammeter [5]. It measures the current going through the circuit while ramping up the voltage in steps of 100 V up to 500 V. The ramp-up is controlled and monitored with LabView based program. If the foil is of good quality and clean, the leakage current remains under 0.5 nA over period of 30 minutes. If the foil has short circuit the measured resistivity drops down to few kilo-ohms or less. In this case when the voltage is ramped up the current does not decrease in time. Instead the current increases with each step to the values obtained from a closed circuit. Figure 2 shows differences between an acceptable foil and a foil with short circuit. The leakage current of the foil with short-circuit can be seen rising with each step while the leakage current of a normally operable good foil can be seen to drop rapidly after each step leveling below the limit of acceptance.

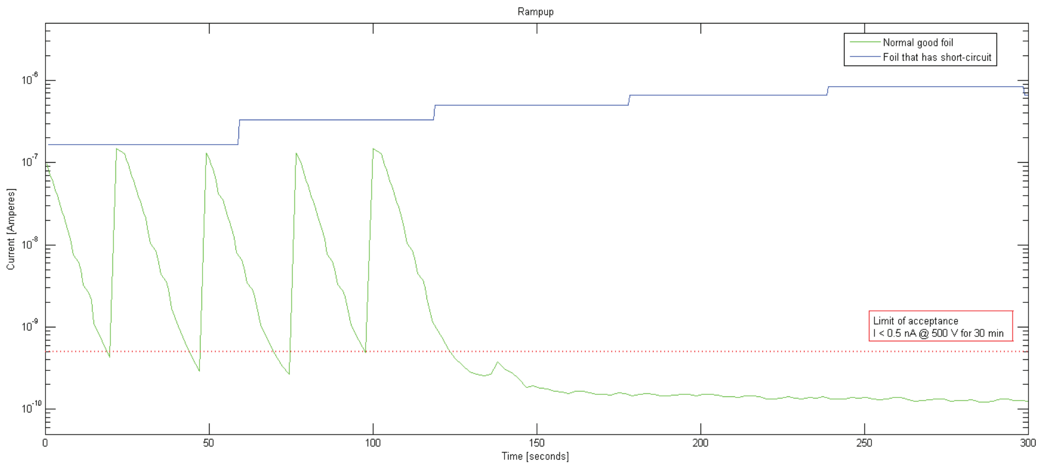

Fig. 2 Leakage currents of an acceptable 10 cm × 10 cm foil marked with green line and a foil with short circuit marked with blue line. The level of acceptance is marked with red dashed line.

To locate the holes that might have the short circuit between the sides of the foil, the foils are scanned with high resolution optical scanning system. It has been primarily developed for quality control of GEM-foils [6]. In this system the standard scanning procedure includes analysis of the dimensions of the foil geometry, such as diameter and pitch of the holes. The standard scanning procedure can also automatically locate and classify the dust particles and defects of different types.

Due to the characteristics of the marks of the discharges on the foil, the detection and classification cannot be performed in simple manner with standard procedures. In this case the imaging is done by utilizing the low reflectivity of carbon. By increasing the intensity of the foreground light and setting the exposure time high enough to saturate most of the image, the areas with higher emissivity can be located and analyzed.

Figure 3 shows a comparison of a mark on a standard image and on an image taken with high exposure time and strong illumination on foreground. The hole that has had a discharge spark in it has a clearly visible darker ring around the walls. These areas appear at the low end of the intensity distribution and can automatically be located.

All the foils are scanned from both sides with standard and overexposure method. The images with areas with intensity below selected threshold are located and mapped. The maps of different sides are compared to locate objects that are visible on both sides of the foil and combined in a single map of the most probable areas of short circuits formed by discharge sparks. An example map of the objects with high emissivity on a standard 10 cm × 10 cm foil can be seen in Figure 4.

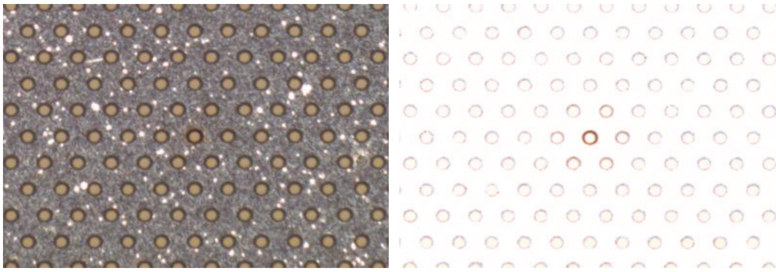

Fig. 3 Comparison of a standard and an overexposured image. Overexposure increases contrast between the mark of a discharge spark and other parts of the foil.

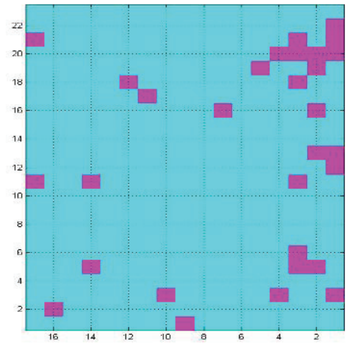

Fig. 4 Map of high emissivity areas located on a GEM-foil. To be mapped the object has to be visible on both sides of the foil.

3. Removing the Short-circuits

3.1. Electrical Removal

Standard method to remove the short circuits on GEM-foils is to apply a high current through the foil. In this method the GEM-foil is connected to directly to a high voltage power supply with high current limit. The voltage is increased in steps up to the level where first sparks are observed and dropped rapidly. The plasma arc forming in the sparks is expected to flake off the carbonized area and thus remove the short circuit.

Figure 5 shows leakage current measurements made on a foil that short circuited after a discharge spark. It was cured by using the high current method. The measurements made with short circuited foil were shorter than the usual 30 min measurement since no changes to the leakage current can be seen. The lines on top of the plot show the leakage current before the high current treatment. Measurements made after the foil was cured show low leakage current of an acceptable foil. The bottom green line was measured right after the treatment and the cyan line above it after the cured foil was used in measurements with Am/Be-source.

The method is should be used only if no other methods can be used. For instance if the disassembly of the detector cannot be done and the foils cannot be cleaned separately. Since the foil might have several points with lower resistivity the discharge spark can occur in any other position further damaging the foil. The spark can form a new short circuit or damage the copper clad surface. Mapping of high emissivity areas before and after a foil was treated with the high current method can be seen if Figure 6. The number of objects with high emissivity has exploded. Though the voltage was ramped down immediately after the first spark, the damage to the foil is beyond repair.

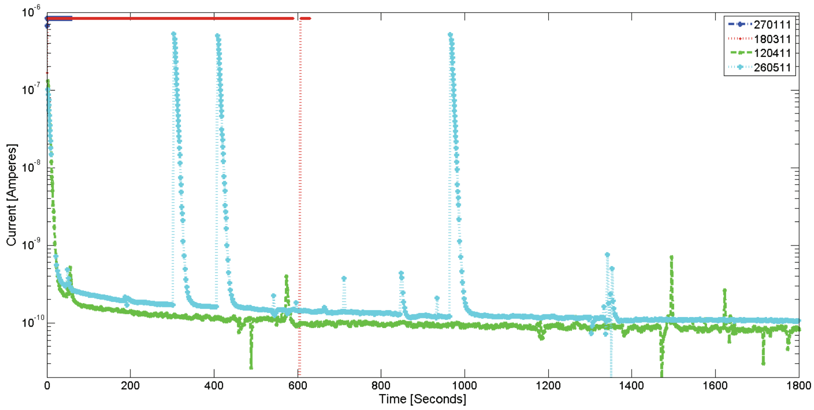

Fig. 5 Leakage currents of a foil that had short-circuited before and after implementing the high current pulse to the detector. Though the leakage current is at acceptable level, several sparks can be seen in the last measurement made right after the foil was used in an application.

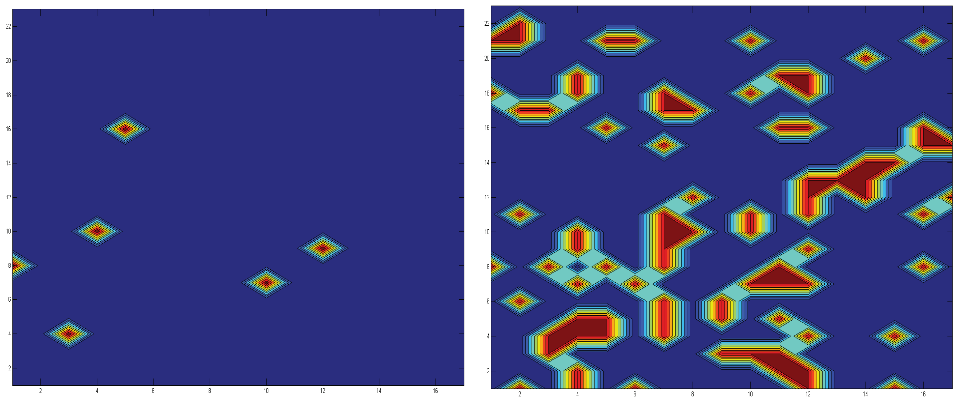

Fig. 6 Mapping of objects with emissivity a GEM-foil before and after the high current pulse was implemented to remove short-circuit. Though the voltage was dropped right after the first spark the foil was damaged beyond repair.

3.2. Acoustic Removal

Acoustic method has been used to measure the tension of a foil after it has been framed. In this method the foil that has been framed is attached to the platform from the four corners and a loudspeaker is placed above it. Using a pulse generator, frequencies from 1 Hz to 20 kHz can be applied. The resonance frequencies were located by observing the changes in laser spot directed on top of the foil surface. From the resonance frequencies the surface tensions of different foils can be compared.

The setup was also connected to leakage current measurement setup to study the changes in leakage current during the vibrations. The measurements were made with voltage of 500V applied over the foil. Since the length of the cables and connections differ from the standard setup the basis current is higher than with the standard setup. The basis current grows also slightly over time due to the slower heating of the system. Figure 7 shows leakage currents of a foil with short-circuit trembled with different frequencies up to 20 kHz. The effect of the resonance frequencies can be seen in the measurement made with the 20 kHz. Instead of constant rise in the current a small drop can be observed after 150 seconds mark.

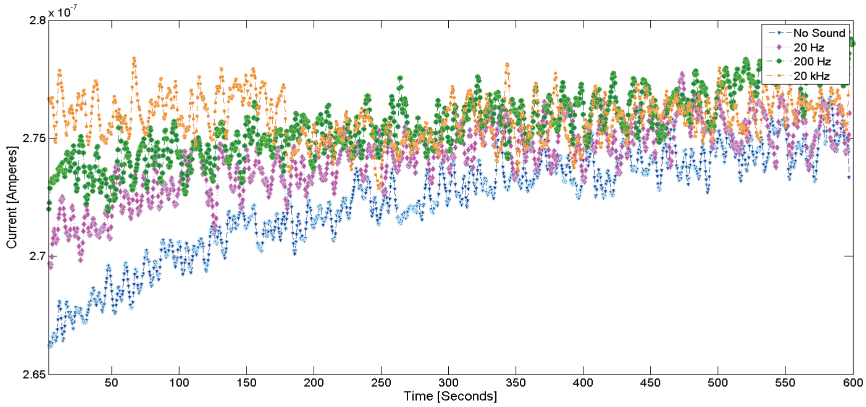

Fig. 7 Leakage currents of a GEM-foil with short-circuit trembled with different acoustic frequencies.

Since the source of short-circuit can also be microscopic dust particles that connect the sides of the foils the vibration frequency used to cure the foil does not need to be at resonance frequency. Even lower frequencies can be effective in removing different types of objects that can be found on the foils surfaces. These microscopic objects are attached to the foil surfaces strong enough not to be removed by pressurized air. Figure 8 shows leakage current measurement made with the acoustic setup where short-circuit was removed from a foil after trembling the foil with 62 Hz frequency.

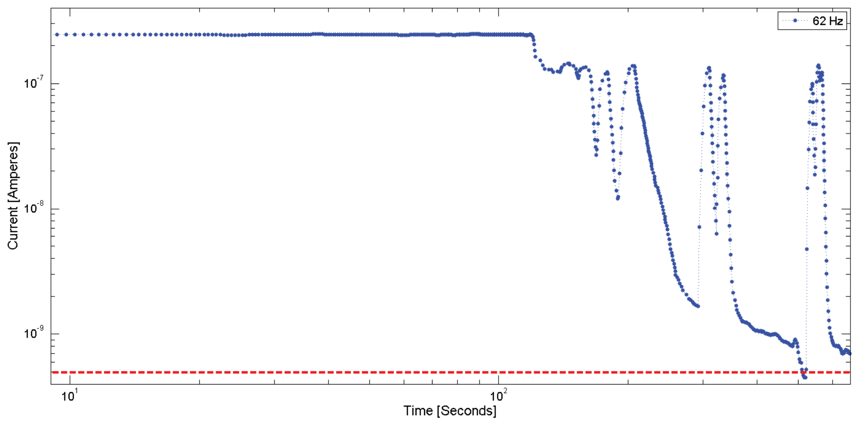

Fig. 8 Leakage current of a GEM-foil under acoustic treatment. Short-circuit is removed after the 100 s mark and the leakage current slowly drops towards the level of acceptance marked with red line. Several sparks can be seen after the short was removed.

3.3. Ultrasonic Removal

The intensity of the acoustic method is expected to be too low to remove the carbonized areas from the foils. To increase the energy of the vibrations, a FinnSonic m15 ultrasonic parts washer was used. The parts washer uses 40 kHz frequency but does not have a specific focusing point for the ultrasound. The foil was placed in ultrasonic bath with de-ionized water for 30 min. After the treatment the foil was dried in a vacuum oven for 24 hours and the leakage currents were measured. The procedure was repeated several times. To increase the effect of the wash, 10% ethanol solution was also tested. No effects to short-circuits were observed.

To focus the intensity of the ultrasonic wash, a VibraCell ultrasonic processor with cleaning probe was used. The probe utilizes frequencies of 20 kHz with maximum power of 500 W. The washing was done again with de-ionized water with 5% of Etax A as detergent. The intensity and the effects of the cleaning were first tested in an area where a microfiber was observed. The first tests were done to study the endurance of the GEM-foil under the treatment and to see the effect on objects that are easy to locate. Figure 9 shows a foil with a microfiber on the surface before and after the treatment. The fiber is removed from the surface without any visible damage to the foil.

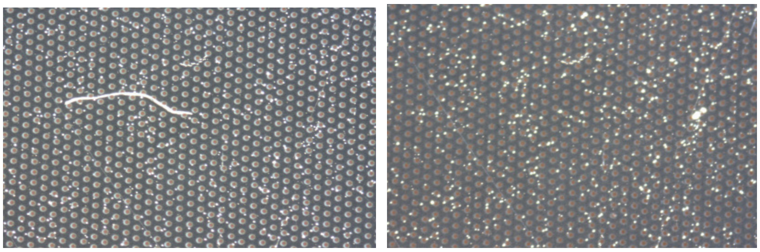

Fig. 9. Surface of a GEM-foil before and after the use of the ultrasonic cleaning probe. The microfiber is removed from the surface without damage to the foil.

The method was also tested on an area which was already known to have carbonized surface. This was created on a surface of a defect with collimated X-rays from ^{55}Fe source [7]. Due to the defect and the irradiation, the area had become weaker and less capable to withstand the shock from the cleaning probe. The vibrations eventually broke the foil surface and conclusive results from the removal could not be made. Figure 10 shows the area under investigation before and after implementing the method on the foil. Figure 11 shows the comparison of threshold distributions plotted from the defect before and after the implementation. The area with low emissivity can be seen decreased in size. From this we could assume that the cleaner can remove carbonized areas at least surface of copper.

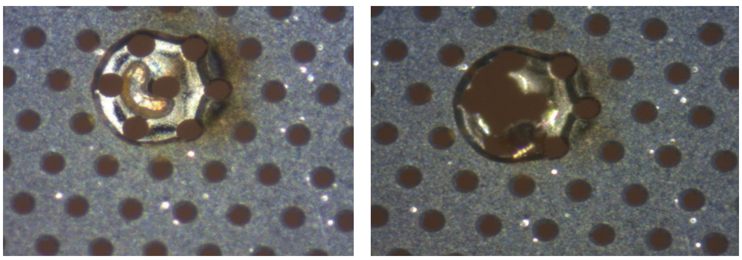

Fig. 10 Area with a defect before and after cleaning with ultrasonic probe.

3.4. Chemical Removal

Since the foils are manufactured and perforated using different caustic solutions, similar methods could be used to remove the carbonized areas from the surfaces of the holes. The solutions to be used should be less erosive to have as minimal effect on the shapes and to create as minimal damage to other parts of the foils as possible. Different solutions were tested but no conclusive results in removing short-circuit with this method was observed.

4. Conclusions

Methods to locate and remove short-circuits on GEM-foils were studied. By overexposure the objects marks of discharge sparks and other similar objects can easily be located and mapped. The mapping can be used to evaluate the performance of different methods used in removal of short-circuits from the foils. Several methods to remove the shorts were studied. From the methods studied the cleaning with ultrasonic probe appears to be the most prominent. It can clean microdust from the surface and clearly has high enough intensity to remove the carbonized areas. Further studies should be made to find the optimal area to be used in the cleaning. Overall, care should be taken in selecting the method to avoid creating damage to the foils.

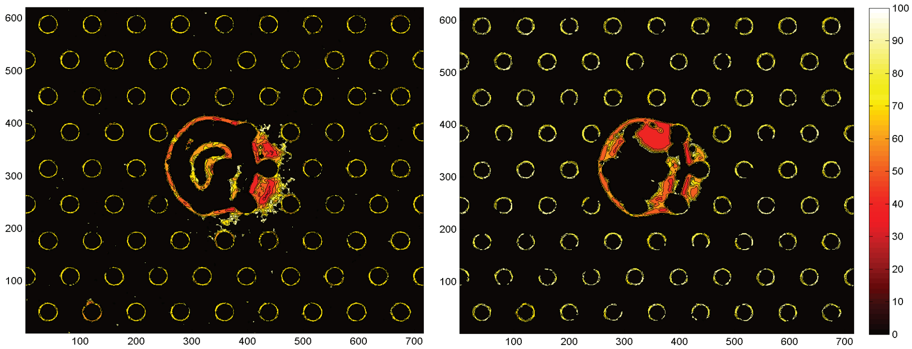

Fig. 11 Intensity distributions of the area before and after the area was cleaned with ultrasonic probe. Low emissivity areas with threshold above 100 are set to 1 to emphasize the areas of interest. Since these distributions are based on standard images instead of overexposured ones, no high contrast between the areas can be seen.

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